Abstract of:

NEO - MIPA

Near-Earth Object
Hazard Mitigation Publication Analysis

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Prepared by:	Dr. Christian Gritzner (Institut für Luft- und Raumfahrttechnik, Technische Universität Dresden)
Checked by:	Dr. Günter Häntschel (EUROSPACE Technische Entwicklungen GmbH)
Project Management:	Dr. Christian Gritzner / Prof. Dr. Stefanos Fasoulas (Institut für Luft- und Raumfahrttechnik, Technische Universität Dresden)

EUROSPACE
TECHNISCHE ENTWICKLUNGEN GMBH
TC SPACE, TECHNOLOGY, APPLICATIONS
POST BOX 2207
09551 FLÖHA

EXECUTIVE SUMMARY

1 General

This document is an analysis of scientific and technical publications on the topic of near-Earth object hazard mitigation systems and strategies. Relevant publications were identified, analysed, and stored in a database.

European researchers experienced in the field of NEO mitigation studies are identified.

2 Background

When our solar system formed about $4.6*10^9$ years ago the Sun, the planets, the moons, and innumerable small objects, the comets and asteroids were formed, too. Because of their small masses compared to the planets, asteroids and comets are susceptible to orbit perturbations. Therefore, it happens that some of them change their orbit and approach the Sun. On their new orbit they can intersect Earth's orbit making a collision possible on time scales of millions of years. These objects are called Near-Earth Objects (NEOs). NEOs approaching Earth's orbit closer than 0.05 AU (about 7.5 million km) are called potentially hazardous objects (PHOs).

Because catastrophic impacts of NEOs with Earth are relatively rare events, the evaluation of the risk cannot be based on personal experiences. In the 1960s it was realised that most craters on the Moon are not of volcanic origin but were formed by impacts of comets and asteroids. Using photographic maps of the Moon and soil samples collected by the Apollo astronauts and the Luna missions, the rate of NEO impacts on the Moon was determined. Applying some corrections these results are also valid for the Earth which orbits the Sun in nearly the same orbit.

The calculated impact rate states that a Tunguska-like impact (a NEO of about 60 meters in diameter destroyed an area of 2200 km² in Siberia in 1908) will happen about once every 100 to 300 years. Larger NEO impacts are less frequent, as shown in figure 1.

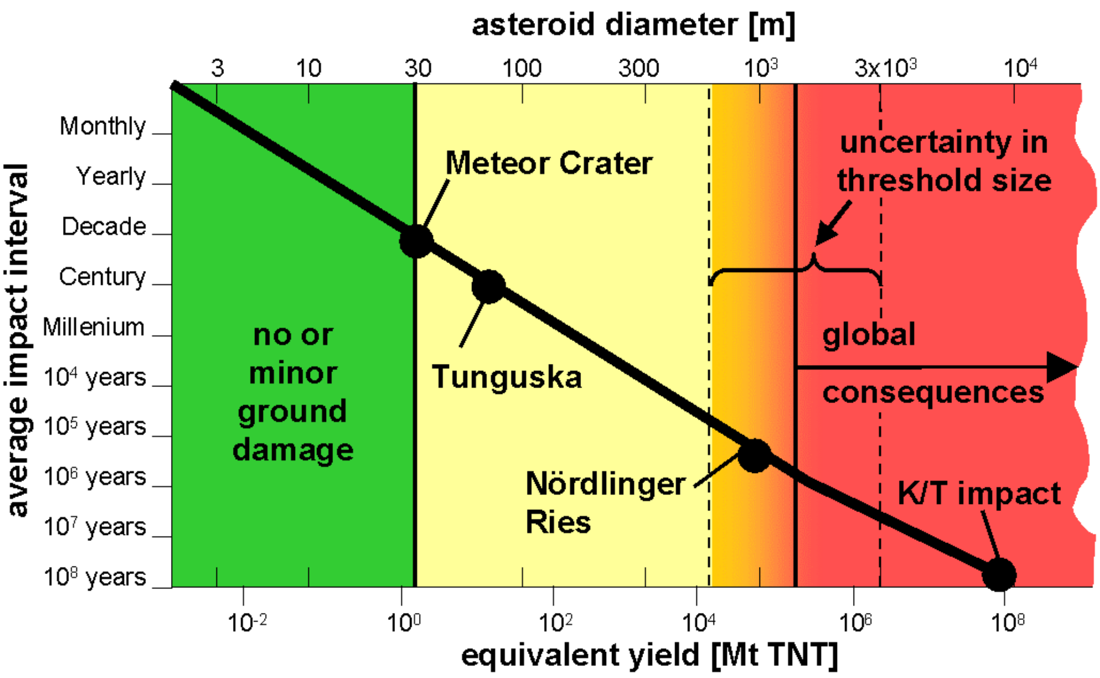

Figure 1:Average impact interval versus size (adopted from: Chapman, C. R., Morrison, D. C., "Impacts on the Earth by Asteroids and Comets: Assessing the Hazard", Nature 367, 1994, p. 37., see ID 063)

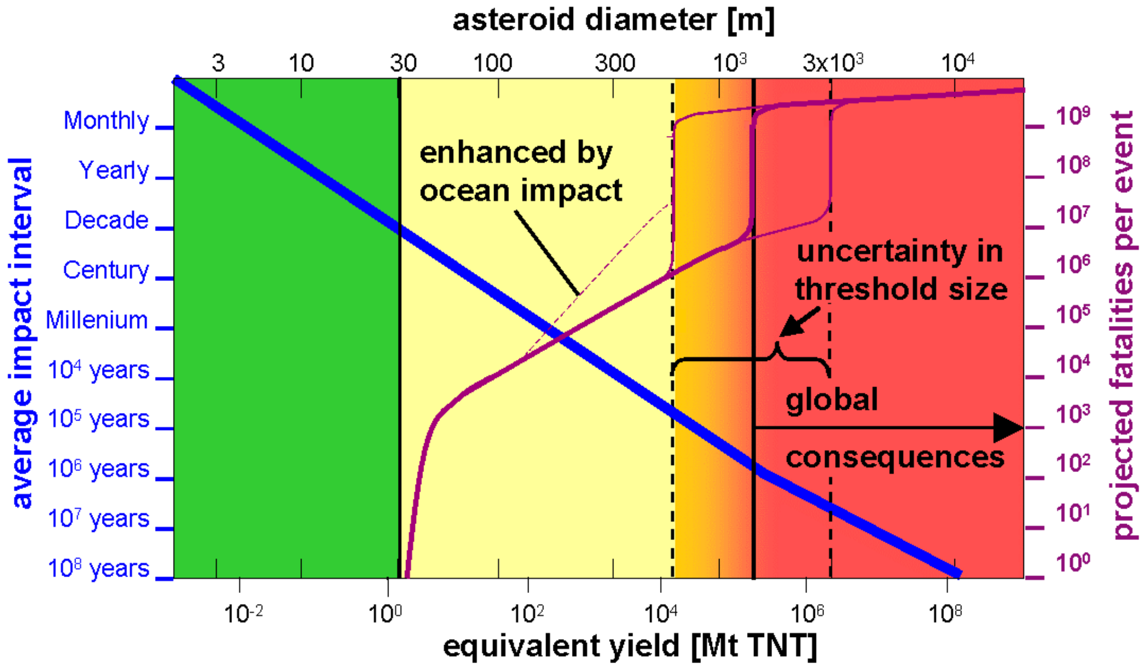

Figure 2:Estimated fatalities per event (adopted from: Chapman, C. R., Morrison, D. C., "Impacts on the Earth by Asteroids and Comets: Assessing the Hazard", Nature 367, 1994, p. 37, see ID 063)

Although NEO impacts are rare events they can occur at any time with disastrous consequences (see figure 2). Due to the low NEO detection completeness of only a few percent a sudden unpredicted impact is the most probable scenario for the next impact event.

The prediction of a coming NEO impact can only be made by an extrapolation of the observed NEO orbits into the future. Therefore, the search for NEOs and the determination of their orbital parameters has to be intensified. The next step is to explore typical NEOs in order to find out more about their composition, density, size, structure, etc. This is important to know for the selection of future mitigation systems.

As shown in this study there are already many papers about possible NEO mitigation strategies and systems. For each possible scenario of a NEO impact the best defence options should be determined in advance, because the warning time before an impact could be very short and studies could be performed right now with only little financial effort saving precious time in case of emergency.

This applies too for the political decision makers, i.e. an international NEO committee should be established with the authorisation to conduct a NEO mitigation mission if needed.

The efforts required for a successful deflection mission in the future would be probably in the order of a large space programme but the potential benefits, e.g. millions of people saved from death, and the prevention of widespread destruction are invaluable.

The threat from NEO impacts and the possible reaction (hazard mitigation) was recognised by several organisations such as US Congress, AIAA, the European Council, ESA, and the UN, which released the following declaration in 1999.

Excerpts from the report of the third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (Declaration of Vienna, 1999), approved by the UN General Assembly:

> *[...] actions should be taken [...] to improve the international coordination of activities related to near-Earth Objects, harmonizing*

the worldwide efforts directed at identification, follow-up observations and orbit prediction, while at the same time giving consideration to developing a common strategy that would include future activities related to near-Earth Objects [...]

The ESA long term space policy (LSPC's Second Report "Investing in Space", ESA SP-2000, May 1999) mentions NEO research as one of the future goals:

- Action:
    - Threat of Cosmic Collision.
- Implemented/On-going:
    - Study of global network for research on NEOs; IMPACT workshop (adoption of Torino Scale); assessment of spaceborne system; use of ISS.
- Supplementary Action:
    - Host the Spaceguard Central Node in ESRIN; study feasibility of an annual contest between European astronomers for detection of close NEOs.

3 NEO Mitigation

3.1 Mitigation Strategies

In order to avoid a collision of a NEO with the Earth there are basically two mitigation strategies:

- fragmentation - destroying the NEO into harmless pieces (smaller than some 30 meters),
- deflection - changing the NEO orbit so that it will miss the Earth by at least a minimal distance,

Fragmentation is a critical process because the fragments will still be more or less on collision course with Earth. There is no guarantee that the resulting fragments will be small enough to cause no ground damage. This method should only be applied to NEO smaller than some 100 meters but there is no general agreement on this limit.

Changing the NEO orbit strongly depends on the available lead time. If there are only some weeks or months until impact there will be a minimal chance to alter the orbit of large NEOs sufficiently because of their high mass (and other reasons as flight time for the mitigation system, etc.). If there is a lead time of many years or decades the needed delta-v is in the order of some cm/s to miss our planet. The minimal fly-by distance is influenced by Earth's gravity and the NEO's relative velocity (gravitational focussing).

3.2 Mitigation Methods

Today there are only three NEO mitigation methods available or within reach:

- chemical propulsion systems,
- impactors, and
- nuclear explosives.

These potential mitigation methods are available but were never tested or applied for mitigation actions. Much development effort would be required to establish a mitigation system. The mitigation methods discussed in the identified publications are described in table 1. Other methods as described in table 1 need much more development effort or are based on technologies that are currently not available. A general problem is the limited payload capacity of the available launch systems. Because nuclear explosives have a higher specific energy content than other systems they are often considered as the “best” mitigation method especially for NEOs larger than about 500 meters in diameter.

Mitigation method	**Description**
chemical propulsion	This method uses a conventional chemical propulsion system which would be attached to the NEO and fired when the thrust vector points to the desired direction (due to the NEO’s own rotation). Fuel generation on some NEOs (which contain water or other useable chemicals) may be possible one day, but this approach would require a very complex in situ facility.
electric propulsion	Electric propulsion systems could be attached to the NEO but have to be operated for long time due to their relatively low thrust level.
exotic methods	Mitigation methods that are probably out of reach for the near future could be antimatter (for propulsion systems or explosions); influencing the gravitational fields; chemical, biological, or mechanical “eaters” which would destroy the NEO, and others.
impactor	A space probe or a specially designed projectile which will hit the NEO at high velocity, spall off NEO material by its kinetic energy, and will therefore deliver an impulse that will change the NEO orbit or destroy it. The planned US space probe “Deep Impact” will direct an impactor to a comet nucleus.
laser systems	Irradiation of the NEO surface by ground-based or space-based laser, x-ray, neutron, and similar systems would vaporise surface material which will stream away from the NEO producing thrust, just as a conventional rocket engine.
mass driver	A mass driver accelerates small mass packages (“fuel”) of some kg by an electromagnetic accelerator device which has to be installed on the NEO as well as a facility to produce these mass packages. This concept could consume huge amounts of NEO material and seems to be very complex.
NEO collisions	This method changes the orbit of a small harmless NEO so that it will collide with a larger NEO on collision course with Earth and change its orbit.
NEO painting	This method would cover the NEO surface and work like a solar sail but with limited acting surface. The resulting thrust is minimal compared to other systems, especially with increasing NEO size.
nuclear explosives	Nuclear explosions could be used in three different ways: (1) as a stand-off explosion in some distance; the radiation produced will heat the NEO surface at very short time so that it is expected to spall away and deliver an impulse to the rest of the NEO, (2) an explosion on the surface which will produce a crater and deliver an impulse due to the ejected mass; the problem of this method is the shock produced which could disrupt the NEO incidentally, and (3) an explosion below the surface, which will increase the ejected mass. Nuclear explosions in space are banned by the Outer Space Treaty and other agreements.
nuclear propulsion	The fuel (hydrogen) is heated in the rocket engine by nuclear fission or fusion processes and is released through a nozzle (just as conventional propulsion systems). Tests have been performed in the 1950s to 1970s but the development was stopped for different reasons.

solar mirror	A mirror will collect solar radiation and focus it onto the NEO surface, where material will be vaporised delivering an impulse to the NEO.
solar sail	A solar sail could be attached to the NEO using the light pressure of the sun, which varies with the distance between NEO and sun. A technical problem is the connection between the sail and the rotating NEO. The resulting impulse is low and the sail area has to be at least in the order of many square kilometres which poses considerable operational and manufacturing problems.

Table 1: Description of NEO mitigation methods

4 Recommendations

From the current point of view the following tasks are recommended:

<u>short-term</u>

- intensified detection and tracking activities for NEOs down to 100 meters (optimal: 30 meters) in diameter,
- NEO exploration (ground based and in-situ space missions, e.g. ROSETTA),
- investigate how Europe could contribute efficiently to the NEO mitigation topic (survey of competence, development of several scenarios of action depending on cost and lead time),
- develop a general concept for NEO mitigation systems based on nuclear and non-nuclear technology, and select an optimal mitigation system for each scenario (i.e. NEO size, orbit, material properties, and lead time),

<u>mid-term</u>

- conduct non-nuclear NEO mitigation testing missions (e.g. impactors, solar mirrors, etc.) in an international co-operation,

<u>long-term</u>

- resources utilisation based on the knowledge from NEO exploration and mitigation (testing) activities, which also could be helpful for some (non-nuclear) mitigation systems,

<u>on-demand</u>

- conduct a NEO mitigation mission, as defined in the preparation activities described above.